

Modelling Human Displacement through Movement Surfaces

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ABSTRACT

This paper introduces a new approach for predicting people displacement by means of movement surfaces. These surfaces can allow the simulation of a person's movement through the use of semantic movement concepts such as those making up the environment, the people who are moving, events that describe a human activity, and time of occurrences. In order to represent this movement we have transformed the trajectory of a person or group of persons into a raindrop path over a surface. As a raindrop flows over a surface looking for the maximum slopes, people flow over the landscape looking for the maximum utility. The movement surfaces are the response to a chained succession of events describing the way a person moves from one destination to another passing through the most affine trajectory to his interest. The three construction phases of this modelling approach (exploration, reasoning and prediction) are presented in this paper. The model was implemented in Protégé and a Java application was developed to generate the movement surface based on a recreational scenario. The results had shown the opportunity to apply our approach to optimise the accessibility of recreational areas according to the preferences of the users of that location.

INTRODUCTION

Spatio-temporal modelling is shifting from models that are able to include the temporal dimension for representing change dynamics to models that need to integrate the dynamic phenomena such as human movement. Turning the process of spatio-temporal modelling into knowledge has spawned a considerable research and modelling efforts despite the fact that tools and technologies are not available yet. A range of new modelling concepts and applications are being developed including the modelling of a continuous economic space (Puu 2008), events through geographical neighbourhoods (Klippel *et al.* 2008), and continuous trajectory transitions (Noyon *et al.* 2007). In contrast, there has also been an increasing influence and prevalence of Mode 2 Science – i.e. science in the context of application rather than the context of discipline- that has encouraged a scientific effort towards exploration to the extent that many scientists now take account of the application context of science (Brilingaitė and Jensen 2007, Prager 2007).

This paper aims to describe our efforts on modelling dynamic collective phenomena using the human movement in recreational areas as the application context. Our model construction is based on three phases as proposed by Peuquet (1994) and Kavouras (2001). These phases are exploration, reasoning and prediction, where concepts and relations can be defined to explain the human movement. During the exploration phase we focus on the modelling of concepts influencing the existence of dynamic collective phenomena as well as their nature, relation and relevance in explaining such a movement. In the reasoning phase we infer the behaviour of “acting classes” by means of the creation of a theoretical movement surface, our new approach to human movement modelling. This surface contains the attraction forces that represent the tendency to increase the level of utility of a person. Finally, in the prediction phase we represent the resultant movement by the steepest gradient of utility in this surface (Batty, 2003).

This utility calculus is based on the personal preferences governing the choice behaviour and decision-making processes carried out during the path selection, similar to a conjoint analysis where consumer preferences are measured to model his behaviour (Dijkstra and Timmermans, 1997). The utility calculus of the movement surface is tackled by materializing these personal preferences by utility functions that are very used in probabilistic choice models (Timmermans et al. 1984). The preferences in travel choice have also allowed us to simulate each individual traveller, like in microsimulation modelling which is becoming increasingly important in traffic demand modelling (Balmer et al, 2006).

THREE PHASES OF MODELLING

In this section we describe the three construction phases of our modelling approach: exploration, reasoning and prediction.

The exploration phase: the description of the human movement phenomenon

In this phase we have formalised the description of what constitutes human movement by the abstraction of the main acting classes in the phenomena. In human movement, we can find different degrees of collectivisation with respect to displacing in a determined moment within a determined spatial frame. The moment determines the finality of the displacement because depending on the hour and day people might move to go to work, go shopping or go on holidays (Kwan and Weber, 2003). The spatial frame determines the surrounding environment, and contains the different spatial variables which have influence in the chosen path for the displacement (for example, temperature, type of network, land use, and slope). Since each person moves in space, according to his individual preferences (Helbin *et al.* 2001), the set of preferences for each person might be different from the set of collective preferences that determine the human movement as a dynamic collective phenomenon.

Another important aspect is the time component. It has been introduced in our model by its relation with the events, because they are the cause of the changes produced in the environment and due to the interaction of people with the environment over time. As a result, our assumption is that human movement is an event, not a state (Galton, 2001). Therefore, we have conceptualised human movement as a dynamic phenomenon which is the result of the interaction between people with the environment surrounding them. Our approach differs from previous gravity models proposed in accessibility studies (Frutos 2004, López 2007) because we have introduced the "Movement Surface" class as the dynamic collective concept that represents the emergent effect of a set of forces which produce movement patterns.

In summary, the acting classes used to represent human movement are Person, Environment, Moment, Event, Preference, Interaction, and Movement Surface. They are further described in Table 1.

Acting Class	Definition	Attributes
Person	Represents the subject of the movement. It could be classified hierarchically into subclasses according to its attributes.	Name, age, address
Environment	Describes the physical space where people are moving, by means of the variables influencing the path election of a person.	All the attributes characterising the environment, such as temperature, humidity, land use, vegetation type.
Preference	Describes the set of requirements that has each person during his displacement.	Utility value and weighting of each environment variable for each person.
Interaction	This abstract class is a function representing the way that an environment is perceived and evaluated by people.	Since it represents a function, it has no attributes
Time	Represents the temporal dimension where the movement happens.	Second, minute, hour, day, month, year.
Event	This class is the responsible for the start of an action and for the modifications occurred in the attributes of the instances of People and Environment classes. It could be classified according to multiple criteria (Zhang 2005), Kaneiwa <i>et al.</i> (2007)	Date, duration
Movement Surface	This class represents the person's tendency to move so as to increase his satisfaction level.	Utility values

Table 1: Overview of the Acting Classes in the exploration phase.

Figure 1 shows the relation among all the classes, stressing the variations suffered by movement surfaces due to events occurred in temporal dimension.

Related to the Preference Class, it is important to note that for each activity (displacement finality) we find a different set of personal preferences. For this reason we have introduced the "preference matrix" to define the way this set of preferences are changing over time. Table 2 illustrates an example of a person preference matrix with the weight (expressed in percentages) of different environment preferences associated to each activity.

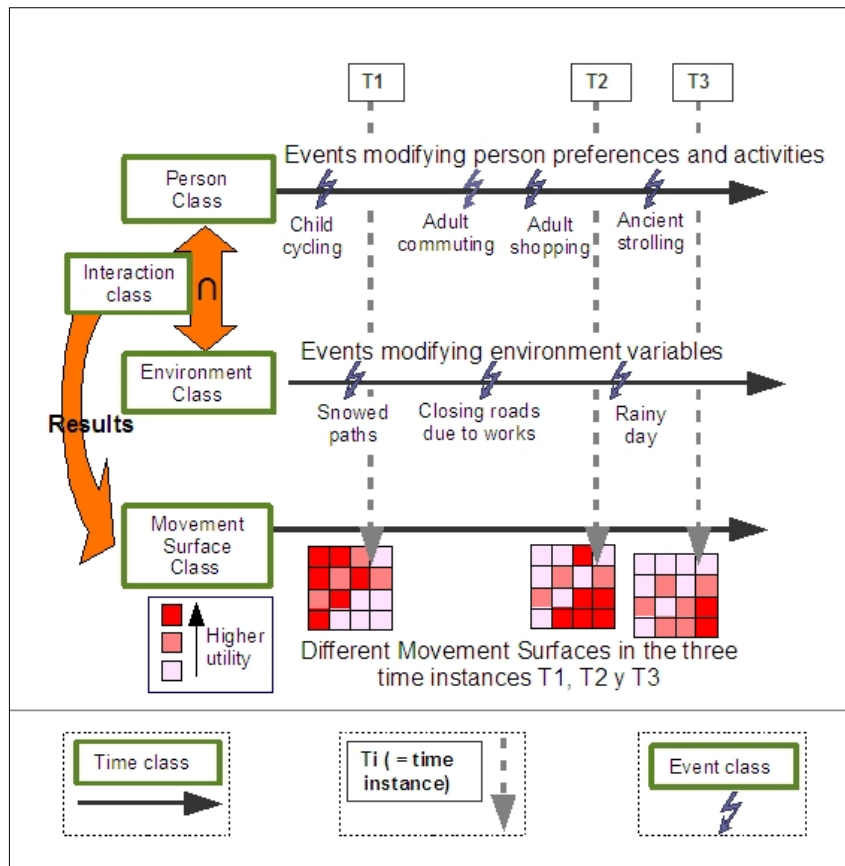


Figure 1: Movement surfaces variation due to events.

ACTIVITY	ENVIRONMENT CHARACTERISTICS			
	Landscape (i.e. vegetation, view shots)	Security (i.e. number of curves, visibility)	Commodity (i.e. slope, temperature)	Velocity (i.e. distance, kind of road)
School transport	20%	70%	10%	0%
Leisure strolling	70%	20%	10%	0%
Commuting	0%	30%	10%	60%
Shopping	10%	20%	20%	50%

Table 2: Preferences matrix example.

The Reasoning Phase: The explanation of the human movement phenomenon by means of movement surfaces

This phase describes the reason why a person moves over an environment. According to the movement law, every object in movement is the consequence to the forces acting over it (Macedo *et al.* 2008). Therefore, the object is the person, and the acting forces are the attraction ones towards the destination passing through the trajectories offering most utility in accordance with the likes or needs of a person or a group of persons. Therefore, the objective in this phase is to compute the utility value calculus in each point of the environment by considering the set of preferences of a person subject of the displacement. As there are several personal preferences to evaluate the utility environment, we have used the multicriteria evaluation to calculate this utility value (Suomalainen 2006, Jankowski 2006).

By combining the SAW method used in multicriteria evaluation (Malczewski 1999) with the accessibility calculus in gravity models, we have obtained the function providing the utility value over the environment:

$$U_i = \sum P_j * G(i, j)$$

- U_i = total utility for each point of the environment
- j = number of requirements of the person.
- P_j = weight of each requirement
- $G(i,j)$ = compliment level of the j requirement in the i point of the environment

As a result of this calculus the movement surface is generated with the utility values in each point of the environment. The concept is similar to a digital elevation model representing the utility value of the environment in each cell of the flow confluence surface (Figure 1).

The Prediction Phase: From a movement surface to trajectories

This phase describes the way a person moves from one destination to another passing through the most affine trajectory to his interest by means of a movement surface. In order to represent this resulting movement we have transformed the trajectory of a person or a group of persons into a raindrop path over a surface. As a raindrop flows over a surface looking for the maximum slopes, people flow over their correspondent flow confluence surface looking for the maximum utility (Hoogendoorn and Daamen, 2003), (Hoogendoorn and Bovy, 2005), (Kitazawa and Batty, 2004), (Hoogendoorn and Bovy, 2002), (Hoogendoorn, 2004). In our model, the trajectories are calculated using this utility values surface in the same way the water flow is calculated from a flow confluence surface as illustrated in Figure 2.

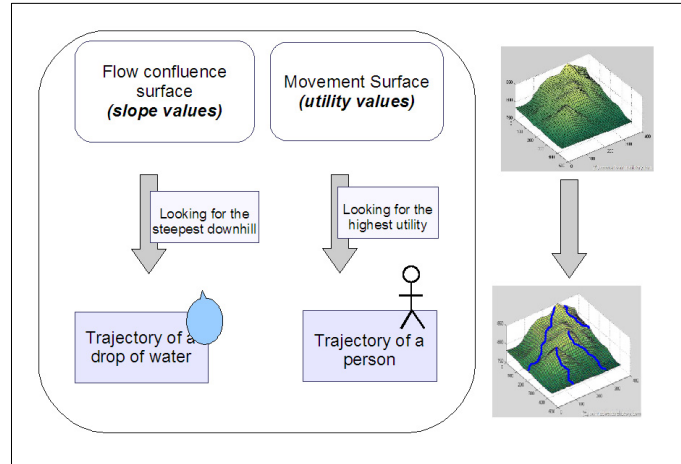


Figure 2: Analogy between Flow Confluence Surface and Movement Surfaces (MDT image extracted from <http://www.adventurehistory.com/>).

IMPLEMENTATION

We have implemented our conceptual model in Protégé, which is an open software that allows the formalisation of the related classes acting in the same phenomenon. Through this implementation we have obtained a formal description consisting of all the acting classes, each one with all its attributes and the relations between them. Furthermore, the implementation in Protégé has allowed us detecting some inconsistencies in our model and making the appropriate corrections.

As a result of this implementation we have obtained the main acting classes and the relations among the instances of the acting classes giving structure to human. Table 3 provides some examples of these relations which are also illustrated in Figure 3.

Some instances of...	Relation	Some instances of...
Time	“Actives”	Event
Person	“Has”	Preference
Event	“Modifies”	Person
Event	“Modifies”	Environment
Person	“Interacts with”	Environment
Person	“Moves over”	Movement Surface

Table 3: Examples of relations implemented in Protégé.

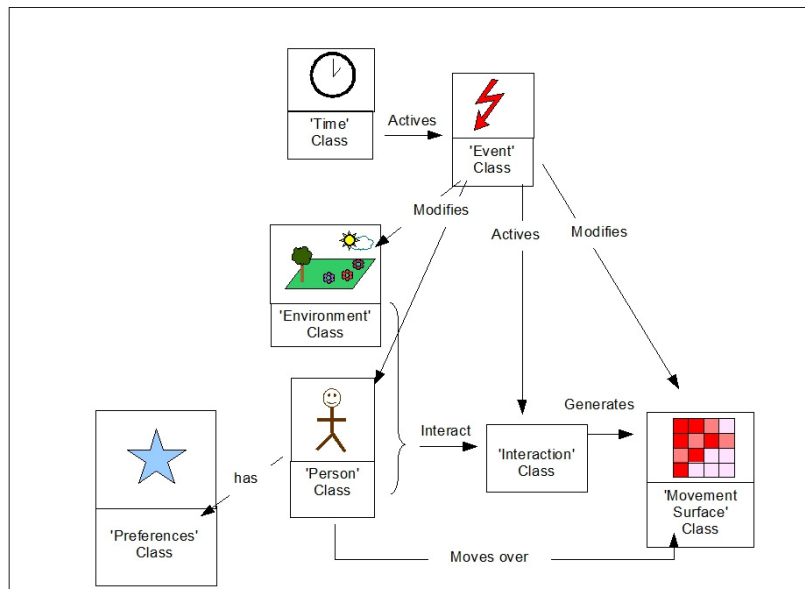


Figure 3: Overview of the acting classes and their relations.

We have also developed a Java application that generates the movement surface and its corresponding trajectory for a recreational scenario. This application consists on an object oriented program composed by the same classes obtained in the formalisation process in Protégé. The scenario for this implementation is based on the displacement of visitors in a natural park. The experiment carried out for tracking the visitors of the Dwingelderveld Park in the Netherlands was used for the design of the simulated scenarios. A detailed survey was also available containing information about the visitors, such as their route preferences, visit purposes and the actual routes followed during their visit through GPS devices.

From the answers of the survey we have inferred the displacement preferences of the visitors considering five aspects:

- **“Path types”**: Each visitor, has different preferences about the followed path, which can be of different kinds: Paved Road, Unpaved Road, Paved Small, Unpaved Small, and Double
- **“Vegetation”**: There are different vegetation densities in the park. Depending on the visit purpose, the visitor has different expectations about the vegetation concentration (forest, sand, wetlands, etc.).
- **“Water proximity”**: There are many lakes along the Park, having different impacts on each kind of visitor. For example, if the visit purpose is observing nature the water preferences are higher than in a dog letting purpose.
- **“Birds watching”**: There are many places along the park where birds can be watched. These places are as well attracting for many visitors of the park who want observe birds.
- **“Attraction preferences”**: Spread by the park there are several attractions points generating many displacements over the park depending on the purpose of the visit: sheepfold, radio-telescope, prayer areas, picnic areas, etc.

The Java application calculates five partial utilities for each point of the environment according to the five criteria or preferences of a visitor. The movement surface is calculated as the total utility from these partial utilities through the function described in the Reasoning Phase:

$$U_{\text{total}} = \sum \text{partial utility (U) for each preference} = \sum W_j * G(i, j)$$

$$U_{\text{total}} = U_{\text{path}} + U_{\text{water}} + U_{\text{vegetation}} + U_{\text{birds}} + U_{\text{attractions}}$$

$$U_{\text{total}} = (W_{\text{path}} * G_{\text{path}}) + (W_{\text{water}} * G_{\text{water}}) + (W_{\text{veget}} * G_{\text{veget}}) + (W_{\text{birds}} * G_{\text{birds}}) + (W_{\text{attrac}} * G_{\text{attrac}})$$

RESULTS

The example described here is the movement surface calculated by for an adult couple visiting the park with the purpose of observing nature. First the application calculates the partial utilities surface for each preference according to this kind of visitor, by following the criteria described below:

- **Path utility:** This kind of visitor prefers paved road rather than not paved road and narrow paths rather than broad paths.
- **Vegetation utility:** Since this visitor purpose is nature observation, he prefers passing through high vegetation concentration.
- **Water utility:** This visitor prefers passing through zones near to the lakes of the park.
- **Birds watching utility:** Since this visitor purpose is nature observation, he prefers passing through high density bird areas.
- **Attractions utility:** There are several attraction points generating high utility to this visitor (teahouse, radio-telescope, graph).

According to these preferences, Figure 4 shows in a darker colour the zones providing higher utility due vegetation density, water proximity, path type, birds presence and attraction points proximity.

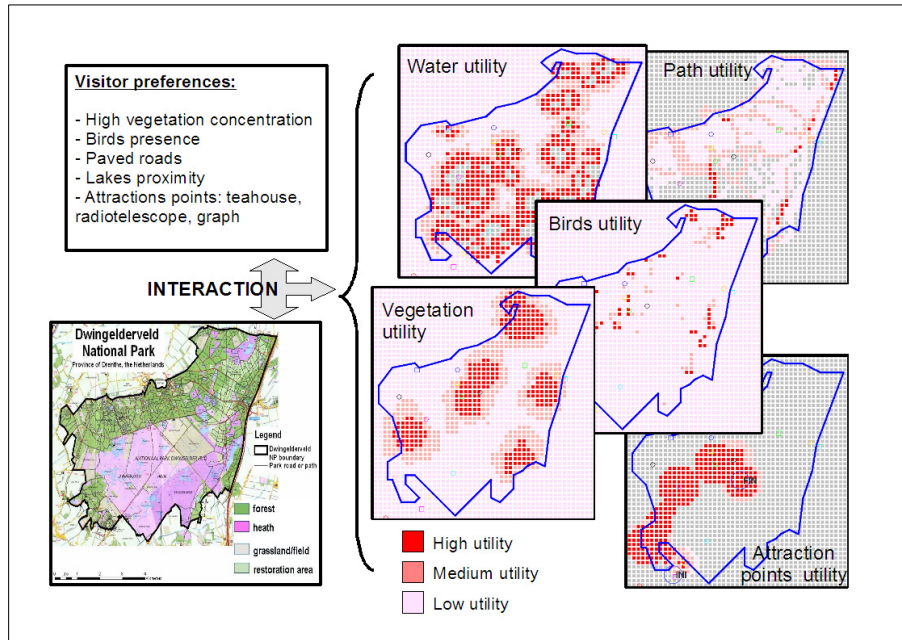


Figure 4: Partial utility surfaces obtained with the application
Topographical map extracted from Terlouw's thesis (2008).

Movement surface

Once the application has calculated the partial utilities for each preference, the total utility is calculated by the weighted sum of all them. The weight applied to each criteria or preference are the following ones:

- Path weigh = 25%
- Vegetation weigh = 10%
- Water weigh = 10%
- Birds weigh = 10%
- Attraction points weigh = 45%

The movement surface calculated from those partial utilities surfaces is shown in Figure 5.

Trajectory

The predicted trajectory is calculated based on the movement surface by means of the steepest gradient utility calculus. The predicted trajectory (black colour) contrasting to GPS observed trajectory (green colour) is shown in Figure 5.

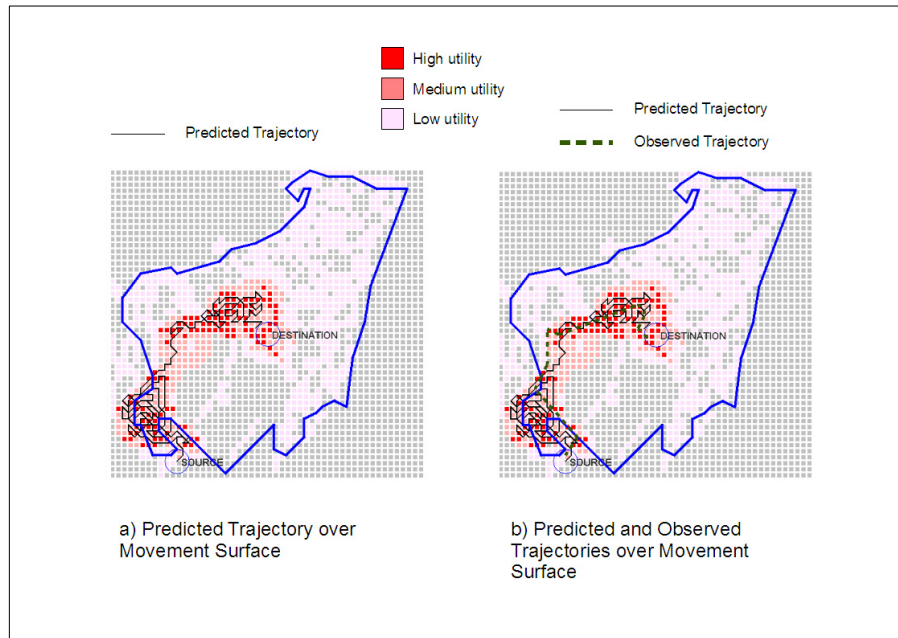


Figure 5: Predicted trajectory versus observed trajectory over a movement surface.

CONCLUSIONS

As a result of the formalisation of acting classes, their correspondent properties and attributes, and the relations between them, it was possible to implement the model into an interactive tool, where different movement surfaces can be obtained for different scenarios. Therefore, this tool allows user to interact with our model using the acting classes, specially the movement surface that considers the person's preferences and environment description within a certain probability.

The results have pointed out to two main aspects. They are one of the following:

- Although we were able to recognise general movement patterns that emerge from people displacement based on personal utility levels, only a general structure in movement prediction is actually represented. This was mainly due to a random component caused by the unpredictability and indeterminism in human behaviour. There are many possible factors causing variations in a predicted displacement such as meeting an unexpectedly element or person, receiving a phone call, etc.
- The possibility of contemplating preferences for journeys allows us to study the movement of individuals who share the same preferences. These groupings can be found in populations of different cultures, who may respond similarly to the same environment. For example, an aborigine will find a different (higher) utility when going through the jungle than a city dweller.

This model is useful for applications in the well-known problem of location-assignment (Fotheringham *et al.* 1995). Another possible uses would be aimed at the planning of routes for individuals in which the purpose is to satisfy the needs or preferences of those individuals, for

example planning tourist routes. It would be similarly applicable to the planning of transport of goods that require specific conditions, for example fragile goods. By checking other kind of simulation models, we can state that our model accomplish (is in agreement with) the four distinguished aspects characterising Geosimulation-style traffic models: (1) depiction of *time* in the sense of that simulated entities reacts according to environment conditions in a single moment, (2) possibility of use "*microscopic*" scales allowing very detailed simulations commonly at the level of individual vehicles and pedestrians, (3) ability to perform *entity-based simulation* from the distinct individual attributes and behaviour of entities, (4) conception of *interaction* as flows between modelled entities and the representation of a more *localized* interaction.(Torrens, 2004)

Further research will focus on the generation of groups based on the individual preferences and the computation of their respective movement surfaces.

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